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ON THE POSSIBLE DISTURBANCE OF A RANGE-FINDER BY ATMOSPHERIC REFRACTION DUE TO THE MOTION OF THE SHIP WHICH CARRIES IT

By LORD RAYLEIGH, O.M., F.R.S.

Read and discussed, 13th February, 1919

[*INTRODUCTORY NOTE.* The following question has been raised by Lieut.-Col. A. C. Williams, R.A.: A ship is travelling at a speed of, say, 25 knots, with the result that the air is compressed to different densities as the ship goes through it. This has very much the same effect as if two prisms were placed in front of the ship. If the target were seen through the end windows of the range-finder, and the two prisms, the effect on the range-finding would be that both prisms would make the range-finder record too long ranges. Supposing the ship to have 75 feet beam, and the range-finder to have 25 feet base and to be placed 50 feet above the ship and 50 feet in rear of the bows, is it possible that the total effect of the pressure of the air could affect the range-finding triangle by as much as half a second of angle?

The Society is indebted to Lord Rayleigh for the following mathematical treatment of this question.—ED.]

THE suggestion has been put forward (as I understand by Lt.-Col. A. C. Williams) that the action of a range-finder, adjusted for a quiescent atmosphere, may be liable to disturbance when employed upon a ship in motion, as a result of the variable densities in the air due to such motion and consequent refraction of the light. That this is *vera causa* must be admitted; but the question arises as to the direction and magnitude of the effect, and whether or not it would be negligible in practice. It is not to be supposed that any precise calculation is feasible for the actual circumstances of a ship; but I have thought that a simplified form of the problem may afford sufficient information to warrant a practical conclusion. For this purpose I take the case of an infinite cylinder moving transversely through an

otherwise undisturbed atmosphere, and displacing it in the manner easily specified on the principles of ordinary hydrodynamics. When the motion of the fluid is known, the corresponding pressures and densities follow, and the refraction of the ray of light, travelling from a distance in a direction parallel to the ship's motion, may be calculated as in the case of astronomical and prismatic dispersion or of mirage. It is doubtless the fact that in the rear of the disturbing body the motion differs greatly from that assumed; but in front of it the difference is much less, and not such as to nullify the conclusions that may be drawn. The first step is accordingly to specify the motion, and to determine the square of the total velocity (q) on which depends the reduction of pressure.

The motion of the fluid, due to that of the cylinder of radius c and moving parallel to x with velocity U , is well known*. The problem may conveniently be reduced to one of "steady motion" by supposing the cylinder to be at rest while the fluid flows past it—a change which can make no difference to the refraction. The velocity-potential is then expressed in polar coordinates by

$$\phi = U \left(r + \frac{c^2}{r} \right) \cos \theta \quad \dots (1),$$

where r is measured from the centre; whence

$$\frac{d\phi}{dr} = U \left(1 - \frac{c^2}{r^2} \right) \cos \theta, \quad \frac{d\phi}{r d\theta} = -U \left(1 + \frac{c^2}{r^2} \right) \sin \theta \quad \dots (2).$$

Here $d\phi/dr$ vanishes when $r = c$ at the surface of the cylinder, and at a great distance the resultant velocity is U , parallel to x . In general

$$\frac{q^2}{U^2} = 1 + \frac{c^4}{r^4} + \frac{2c^2}{r^2} (\sin^2 \theta - \cos^2 \theta) = 1 + \frac{c^4}{r^4} + \frac{2c^2}{r^2} (y^2 - x^2) \quad \dots (3).$$

As will be stated more at length presently, the reduction of pressure and density is proportional to q^2 , so that the (abnormal) optical retardation of a ray parallel to x is proportional to $\int q^2 dx$, in which the upper limit for x may be treated as infinite. The difference of retardations for two infinitely near rays parallel to x , divided by the distance between them, gives the angle of refraction, which is thus represented by $\frac{d}{dy} \int q^2 dx$, or by $\int \frac{dq^2}{dy} dx$, since the limits of x are the same for both. Now

$$\frac{d}{dy} \left(\frac{q^2}{U^2} \right) = (c^4 - 2c^2 x^2) \frac{d}{dy} \left(\frac{1}{r^4} \right) + 2c^2 \frac{d}{dy} \left(\frac{y^2}{r^4} \right);$$

and, since

$$dr/dy = y/r,$$

$$\frac{d}{dy} \left(\frac{1}{r^4} \right) = -\frac{4y}{r^6}, \quad \frac{d}{dy} \left(\frac{y^2}{r^4} \right) = \frac{2y(x^2 - y^2)}{r^6},$$

so that

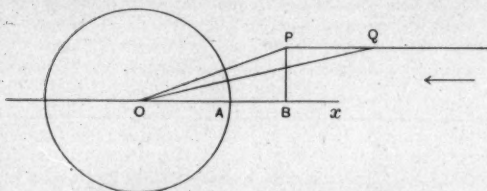
$$\frac{d}{dy} \left(\frac{q^2}{U^2} \right) = \frac{4c^2 y}{r^6} (3x^2 - y^2 - c^2) \quad \dots (4).$$

In the integration with respect to x , y is constant, say β , and if α, β be the rect-

* See Lamb's *Hydrodynamics*, § 68.

angular coordinates of the point P in the figure at which the refraction is to be estimated, the limits for x are a and ∞ . Thus

$$\int_a^\infty \frac{d}{dy} \left(\frac{q^2}{U^2} \right) dx = -4c^2\beta(\beta^2 + c^2) \int_a^\infty \frac{dx}{r^6} + 12c^2\beta \int_a^\infty \frac{x^2 dx}{r^6} \dots (5).$$



$$OA=c, OB=a, PB=\beta, QOB \text{ or } POB=\theta, OQ \text{ or } OP=r.$$

At this point it is convenient to re-introduce θ , where $x = \beta \cot \theta$, and

$$dx = -\beta \sin^{-2} \theta d\theta.$$

We have
$$\int \frac{dx}{r^6} = -\int \frac{\beta \sin^{-2} \theta d\theta}{\beta^6 (1 + \cot^2 \theta)^3} = -\frac{1}{\beta^5} \int \sin^4 \theta d\theta.$$

The upper limit ∞ for x corresponds to $\theta = 0$; the lower limit a corresponds to what after the integration we may still denote by θ , where $a = \beta \cot \theta$. Thus

$$\int_a^\infty \frac{dx}{r^6} = \frac{1}{\beta^5} \int_0^\theta \sin^4 \theta d\theta = \frac{1}{4\beta^5} \left(\frac{3}{2}\theta - \sin 2\theta + \frac{1}{8} \sin 4\theta \right) \dots (6).$$

Also
$$\int \frac{x^2 dx}{r^6} = -\frac{1}{\beta^3} \int \cos^2 \theta \sin^2 \theta d\theta = -\frac{1}{8\beta^3} \left(\theta - \frac{1}{4} \sin 4\theta \right),$$

and
$$\int_a^\infty \frac{x^2 dx}{r^6} = \frac{1}{8\beta^3} \left(\theta - \frac{1}{4} \sin 4\theta \right) \dots (7),$$

θ now referring, as above, to the point for which $x = a$. Using (6) and (7) in (5), we have

$$\begin{aligned} \int_a^\infty \frac{d}{dy} \left(\frac{q^2}{U^2} \right) dx &= -\frac{c^2(\beta^2 + c^2)}{\beta^4} \left(\frac{3}{2}\theta - \sin 2\theta + \frac{1}{8} \sin 4\theta \right) + \frac{3c^2}{2\beta^2} \left(\theta - \frac{1}{4} \sin 4\theta \right) \\ &= \frac{c^2}{\beta^2} \left(\sin 2\theta - \frac{1}{2} \sin 4\theta \right) - \frac{c^4}{\beta^4} \left(\frac{3}{2}\theta - \sin 2\theta + \frac{1}{8} \sin 4\theta \right) \dots (8), \end{aligned}$$

in which, if we please, we may substitute $r \sin \theta$ for β , so that r, θ are the polar coordinates of the point of observation.

Thus

$$\begin{aligned} \int_a^\infty \frac{d}{dy} \left(\frac{q^2}{U^2} \right) dx &= \frac{c^2 \sin 2\theta - \frac{1}{2} \sin 4\theta}{r^2 \sin^2 \theta} - \frac{c^4 \frac{3}{2}\theta - \sin 2\theta + \frac{1}{8} \sin 4\theta}{r^4 \sin^4 \theta} \\ &= \frac{c^2}{r^2} f(\theta) - \frac{c^4}{r^4} F(\theta) \dots (9), \end{aligned}$$

as we write it for brevity. It now remains to discuss (9) as a function of r and θ , under the limitation, however, that $r > c$.

When θ is small,

$$f(\theta) = 4\theta, \quad F(\theta) = \frac{4}{5}\theta,$$

so that (9) becomes

$$4\theta \left(\frac{c^2}{r^2} - \frac{c^4}{5r^4} \right) \dots (10),$$

vanishing when $\theta = 0$, as was to be expected, since this is a line of symmetry. Inasmuch as $r > c$, (10) takes its sign from θ .

θ	$f(\theta)$	$F(\theta)$	(9) when $r = c$	(9) max.
0°	0	0	—	—
10	.6840	.1404	.5436	—
20	1.2856	.2859	.9997	—
30	1.7320	.4419	1.2901	—
36	1.9021	.5436	1.3585	—
40	1.9292	.6159	1.3133	—
50	1.9696	.8173	1.1523	—
60	1.7320	1.0605	.6715	.7072
70	1.2855	1.3680	-.0825	—

The table gives values of f and F for certain angles of θ . In the fourth column are entered the values of (9) when $r = c$, that is on the surface of the cylinder. So far as $\theta = 50^\circ$ these are the highest admissible. For example at 50°

$$\begin{aligned} (9) &= .8173 (2.4098c^2/r^2 - c^4/r^4) \\ &= .8173 \{ (1.2049)^2 - (1.2049 - c^2/r^2)^2 \}. \end{aligned}$$

So long as $r > c$, the value of (9) increases as r diminishes, and the greatest admissible value occurs at the limit $r = c$. This state of things continues so long as $f > 2F$. At 60° this condition has ceased to hold, and the maximum value of (9) occurs when $r > c$. We may write generally

$$(9) = F \{ (f/2F)^2 - (f/2F - c^2/r^2)^2 \}.$$

The maximum of (9) occurs when $c^2/r^2 = f/2F$, and the maximum value is $f^3/4F$. For $\theta = 60^\circ$, the maximum is .7072. When $\theta = 70^\circ$, (9) itself has changed sign, the transition occurring when $F = f$.

For our present purpose we may take the highest value of (9) as 1.36.

The general dynamical equation connecting pressure (p) and density (ρ) with velocity (q) in steady motion is

$$\int \frac{dp}{\rho} = C - \frac{1}{2} q^2 \dots (11).$$

It will suffice if we employ Boyle's law for the connection of p and ρ , that is $p = V^2 \rho$, where V is the velocity of sound. Thus

$$V^2 \log (\rho/\rho_0) = \frac{1}{2} (U^2 - q^2)$$

if ρ_0 correspond with $q = U$, as at a distance from the cylinder. Or, since the variations of density here contemplated are very small,

$$\frac{\rho - \rho_0}{\rho_0} = \frac{U^2 - q^2}{2V^2} \dots (12).$$

Passing now to the optical side of the question, we have to consider the retardation experienced by a ray parallel to x , due to the variable density. In

accordance with a general principle, this when small enough may be calculated along the original ray, although the actual ray now follows a somewhat different course*. Thus if $\delta\mu$ be the change of refractive index due to q , the retardation may be taken to be $\int_a^\infty \delta\mu dx$, and the angle χ through which the ray at P is turned is

$$\chi = \int_a^\infty \frac{d\delta\mu}{dy} dx \quad \dots(13).$$

Now for air at 0° C. and 760 mm. pressure $\mu = 1.000292$, so that

$$\delta\mu = .000292 (\rho - \rho_0)/\rho_0 = -.000146q^2/V^2 \quad \dots(14).$$

Accordingly

$$\chi = -\frac{.000146U^2}{V^2} \int_a^\infty \frac{d}{dy} \left(\frac{q^2}{U^2} \right) dx \quad \dots(15),$$

and the integral is the quantity already calculated under (9). It will be observed that the effect is independent of the absolute size of the obstacle, and is proportional to the square of the fluid velocity U . As regards the sign of the effect, we see that, so long as (9) is positive, the retardation diminishes as y increases, and thus a ray originally parallel to x is bent *inwards*. This action in a range-finder leads to an over-estimate of the distance.

We may now consider the actual magnitude of χ . If we take the highest value of (9), viz. 1.36, we have

$$\chi = -.000199U^2/V^2 \quad \dots(16).$$

To take a numerical example, let us suppose that

$$U = 25 \frac{\text{miles}}{\text{hours}} = 1120 \frac{\text{cm.}}{\text{sec.}},$$

and

$$V (0^\circ \text{ C., } 760 \text{ mm.}) = 33100 \frac{\text{cm.}}{\text{sec.}}.$$

The angle is then

$$-\chi = 2.27 \times 10^{-7}.$$

This is in circular measure, and it corresponds to .0467 second. An error of a twentieth part of a second may be considered negligible.

The corresponding problem with a sphere in place of the cylinder could be treated, but it is rather more complicated. It does not appear necessary to enter upon it here.

The objection may present itself that the motion in two dimensions round a cylinder does not well represent the case of a ship. This must be admitted; but it seems clear that a range-finder, carried well above the deck of a ship, would be much *less* liable to be disturbed in the manner discussed.

* For an application to the resolving power of prisms, reference may be made to *Phil. Mag.* 8 (1879), 269; *Scientific Papers*, Vol. 1. p. 425.

DISCUSSION

Dr A. Barr communicated the following remarks:

I have read with much interest Lord Rayleigh's communication. It is very satisfactory to have such convincing proof that the disturbances of range-finding observations by atmospheric refraction due to the motion of the ship carrying the range-finder can have so little effect. We (Barr & Stroud, Ltd.) had ourselves concluded that the effects, in the worse cases imaginable, would be very small, although we had not made any estimate of the effect due to the motion of the air around an obstruction in front of the range-finder, such as Lord Rayleigh has dealt with so clearly and fully.

We made some rough calculations of the effect of the compression of the air in front of a range-finder on board a moving ship, making necessarily some very wide assumptions. Lord Rayleigh's remark that, "it is not to be supposed that any precise calculation is feasible for the actual circumstances" applies generally to all such calculations. The forms of the isobaric interfaces in front of a solid of complex form moving through air cannot be calculated and these interfaces are, of course, in any case rapidly changing in form.

We considered the very extreme case of denser masses of air of prismatic form being formed in front of the windows of a range-finder, and, even in that case, it appeared that at a speed of 25 knots the effect would not be so great as a $1/20$ second. The calculation had none of the scientific interest of Lord Rayleigh's investigation which is founded on a definitely specified set of conditions and upon the true forms of the isobaric interfaces resulting. The approximate correspondence between the results we got and those in Lord Rayleigh's paper is of no significance, except that both results are so small. Our calculations were founded upon impossible physical conditions and were only made to find if a result that would be appreciable could follow from the compression which must take place in front of any solid moving through air.

It may be interesting to state that the smallest angle we assume to be capable of detection in range-finding practice is about one-third of a second; Lord Rayleigh's calculation shows that, even in the very extreme case that he assumes, the effect would not be so much as a sixth part of the smallest angle that can be detected under the best conditions of observation with a service range-finder.

Mr H. Spencer Jones communicated the following remarks:

The conclusions which Lord Rayleigh arrives at in his paper are in agreement with those which I obtained from independent calculations made when the possibility of some atmospheric disturbances affecting range-finders was first raised. The conclusion arrived at agreed with what one would have considered *a priori* probable. It does not seem possible that, if the streaming motion of the air past the ship produced sufficient disturbing action appreciably to modify the observed ranges, the effect would not have been long ago discovered.

I believe that occasionally several ships will at the same time record ranges in error by the same amount, but whether the errors are always positive or whether sometimes negative I am not aware. The question suggests itself whether some peculiar and transient condition of the atmosphere could account for the phenomenon. The only way in which I think it possible would be to suppose there were a stratum of air of different density through which the range-finders were looking very obliquely. The supposition is a very improbable one, a somewhat large difference of density being required, but it is possible that at times some such effect might occur.

The difficulty attending any such attempted explanation is the magnitude of the effect which it is sought to explain.

Instructor-Commander T. Y. Baker communicated the following remarks:

The Optical Society certainly deserves our thanks for having taken up the question raised by Col. Williams and having obtained this very interesting paper by Lord Rayleigh. It happens so often that information of a similar character is required by practical men and cannot be obtained by them because they do not know to whom to apply for advice. At the same time scientific workers on the more theoretical side are often not aware, unless their attention is specially directed to it, that such information is needed and as a result nothing gets done. One of the functions which a Society such as the Optical Society can fulfil is to put the practical man and the scientist into touch with one another and to ensure that a point on which information is desired is referred to the most competent people to deal with it.

The problem put by Col. Williams is one which no mathematician could possibly hope to solve in exact terms. Some sort of simple geometrical form for the shape of the ship must be assumed, which will permit of the application of the ordinary equations of hydrodynamics, and these simple geometrical forms are exceedingly few; the circular and elliptic cylinders of infinite length, the sphere and the ellipsoid are practically all that can be treated in exact terms. Lord Rayleigh has chosen to represent his ship by an infinitely high vertical circular cylinder: obviously such a very imperfect representation of the shape of the ship that I think the most extreme caution is necessary in drawing any conclusions from his calculated results. There ought to be a comparatively high "factor of safety" applied to any such result on account of the dissimilarity between his assumptions and the actual facts, a factor which I should say ought to be not less than 10; so that where he has obtained a deflection of a ray of light amounting to one-twentieth of a second that should be multiplied by 10 for the purpose of giving a possible maximum deviation in the real case. I do not say that the deviation in the real case will be half a second, but that in view of the assumptions made for the purpose of calculating the deviation of a ray the aberration effect should only be dismissed as negligible if it is less than one-tenth of the minimum amount that we are prepared to consider.

Further I desire to draw attention to the fact that Lord Rayleigh's one-twentieth of a second deviation will occur at each end of the range-finder in opposite senses

so that there will be a change in the convergence angle at the target of one-tenth of a second; and that the value ascribed to U is certainly too low as the case should be considered of a ship steaming full speed against a head wind. A relative wind-speed of 60 m.p.h. is by no means too high to be assumed in such case, altering the one-tenth of a second to three-fifths of a second. With a nine-foot range-finder on a range of 20,000 yards the corresponding error is 400 yards, which is by no means negligible. Again, the error in the convergence angle is multiplied by the magnification, say 30, of the range-finder telescopes and would subtend at the observer's eye 18 seconds of arc. Some years ago as a result of experiments carried out at Greenwich I formed the conclusion that an untrained observer could make the coincidence adjustment with a precision of less than 10 seconds at the eye, and I understand that experiments now being carried out at Messrs Barr and Stroud's works show that for trained observers the figure should be put very much lower.

In view of the above considerations I come to exactly the opposite conclusion to Lord Rayleigh, and consider that there is no justification at all for considering that the effect of atmospheric disturbance is negligible. On the other hand I think Lord Rayleigh's figures show beyond a shadow of doubt that further investigation is necessary.

Such investigation might be both practical and theoretical. By setting a range-finder up in a wind-channel such as is used at Teddington for aeroplane experiments some sort of measured results could be obtained with different wind velocities. The theoretical investigation might cover those cases which approximate more closely to the actual state of affairs than the infinite circular cylinder, and which are at the same time capable of exact mathematical solution. For instance, the control-platform is not very far distant in shape from an ellipsoid with its longest axis in the direction of the wind. Another point which merits consideration is whether the motion of the air round the ends of the range-finder itself may not be a cause of deviation of the light. Are there no means of attacking the hydrodynamical problem of a circular cylinder of finite length travelling transversely through a fluid so as to obtain an approximate solution of the pressure distribution in the neighbourhood of the ends? I am under the impression that some such approximate solution has been obtained for a circular plate moving through still air in a direction at right angles to its plane, and should be very interested to hear whether anything similar has been done or can be done for a finite circular cylinder.

Lieut. Wilfred Taylor communicated the following remarks:

I consider that a modern service range-finder will detect an angle of about 10 seconds divided by the horizontal magnification.

While ranging from ships steaming at 20 to 25 knots I have never definitely detected any error due to the cause under discussion. The range-taker's work is, from a variety of causes, made so difficult that slight errors due to air compression are found to be inseparable from greater errors, due to the movements of the ship making it extremely difficult to concentrate on the target.

If all the range-finders are adjusted previous to a run and the ranges taken by each instrument are plotted, it will be found that the maximum and minimum ranges, taken on the same target at the same moment, show a variation of several seconds. Occasionally they will all read long or all read short, though I have never been able to trace any regularity in their behaviour.

While ranging over land I have observed phenomena which may have a definite bearing on the subject under discussion. Unfortunately my notes are not available at present, and I am therefore quoting from memory. At one time I carried out some tests with three range-finders and three times a day took sets of readings on various known objects. On certain occasions it was found that the instruments would read correctly on objects in a westerly direction, while reading long on objects in an easterly direction. The errors were of the order of one second and the three instruments behaved similarly. Unfortunately I cannot without my notes say what was the direction of the wind.

While ranging from stationary ships at Scapa Flow I have noted occasions when the two instruments under trial read one or even two seconds long on one known range while reading correctly on the others, which were in various directions and over sea and land. There was, moreover, no reason for believing one of the distances to have been incorrectly worked out, as on most occasions all would read correctly. (Errors arising from the position of the anchor and the swinging of the ship on the anchor chain are made negligible.)

Possibly there may be some explanation for these observed irregularities, apart from the compression of the air around the instrument, but the fact remains that unaccountable errors are observed from time to time which are not of a negligible character.

A good modern range-finder would appear to have reached a stage of development where the causes of error exterior to the instrument are greater than those in the instrument itself.

Very valuable results would probably be obtained in a wind-channel.

Lt.-Col. A. C. Williams agreed with Commander Baker's remarks. He thought it was very important that experiments should be carried out to test the theory.

Major E. O. Henrici suggested that experiments might be carried out in the wind-channels at the National Physical Laboratory.

The President (Prof. Cheshire) said that one of the great lessons the war had taught us was that contrary to the usual proverb, an ounce of theory was worth a pound of practice. He thought this was clearly a case for Naval Commanders to test under service conditions.

Mr T. Smith welcomed the suggestion that experiments on the point discussed in the paper should be made in a wind-channel where the conditions were under control. It was of interest to have the theoretical results obtained by Lord Rayleigh on the basis of conventional hydrodynamics, but he understood that there were wide divergencies between the motion of fluids found experimentally and those predicted by hydrodynamical theory. Experimental confirmation of the theoretical results was therefore of great importance.

Lord Rayleigh communicated the following reply:

I have read with interest the remarks upon my paper made by men better informed as to the capabilities of range-finders than I can pretend to be. I fully concur in the opening observations of Commander Baker as to the advantage to both parties that would arise from a further consultation between practical men and mathematicians and physicists. I also agree in the recommendation of actual experiment upon the subject in a wind-channel. In the course of such experiment questions often arise which would hardly suggest themselves to merely theoretical workers.

But I desire to point out that I especially avoided formulating any general conclusion, and that the only thing that I said was negligible (I believe on good authority) was an error of $1/20$ second!

There may be different opinions as to how far conclusions for an infinite cylinder throw light on the case of the ship. Certainly my own impression is that the cutting away of the further parts of the cylinder would diminish the disturbance under discussion.

DEPOSITS ON GLASS SURFACES IN INSTRUMENTS

By L. C. MARTIN, D.I.C., A.R.C.Sc., B.Sc.

AND MRS C. H. GRIFFITHS, M.Sc.

Read and discussed, 13th February, 1919

SYNOPSIS.

Phenomena to which the term "film" has been applied.

Position of occurrence of "films" in instruments.

Probable effect of lubricants in causing formation of a deposit.

Desirable qualities in a lubricant for use in optical instruments.

Summary of results of information concerning deposits.

Classification of "films" according to their microscopic appearance.

Experiments to test the effects of

- (a) method of cleaning the glass surface,
- (b) previous treatment of glass surface,
- (c) moist air and heat,
- (d) lubricants,
- (e) kind of glass used,
- (f) bronzing solution.

Further experiments on effects of lubricants.

Collection and comparison of results on stability of glasses.

Conclusions.

SECTION I. INTRODUCTION.

In a previous communication to the Optical Society Mr H. S. Ryland* has discussed precautions necessary to prevent the appearance of deposits and pitting on glass surfaces in instruments; but while the methods therein described have proved of value in minimising trouble of this nature it has been shown that their adoption does not in all cases lead to its complete elimination.

Before describing various experiments which have been carried out in the Department of Technical Optics, Imperial College of Science and Technology, to detect the cause or causes of this "filming," it will be as well to summarise the information which we have been able to glean from outside sources.

Firstly, the term "film" is somewhat misleading, as it has been applied indiscriminately to several distinct types of surface uncleanness amongst which the most usual are

- (1) A deposit of small globules.
- (2) Pitting of glass surfaces; and definite chemical decomposition.

* H. S. Ryland, *Trans. Opt. Soc.* 19 (1918), 178.

- (3) Appearances partly resembling both (1) and (2), or apparent smears of dirty material.

The globular deposit is most common, but varies greatly in appearance. It bears almost exactly the characteristics of a deposit of dew on glass and tends to form along streaks or cleaning marks. The deposit, however, does not evaporate in dry air. It is easily removed by distilled water, and the chemical reaction is said to vary in different cases. As is shown in this paper it may easily be imitated by exposing glass to the vapour of hydrochloric acid (arsenical bronzing solution is especially effective), when the deposit produced resembles the appearances in many instruments in a very marked degree. A similar deposit has been formed on a freshly etched graticule left in a paper envelope. In freshly assembled instruments such formations have sometimes been apparent after two or three weeks.

The subject of the chemical stability of glass surfaces is one on which a great deal of work has been done, and much information has been published*. In spite of the care with which experiments have been made, however, the results of the experience of actual weathering of glasses are difficult to coordinate with their behaviour under more artificial conditions, notably in the autoclave and iodeosin tests. The question has been raised as to the possibility of appreciable difference in weathering properties due to comparatively slight changes in chemical composition, and so far the question has not been satisfactorily settled.



Fig. 1. Artificially produced water film.

The third appearance mentioned above has been met with chiefly in instruments returned from tropical use. It can be imitated in the laboratory, as has been shown by Dr Tinkler, by rapidly forming and evaporating dew deposits on a clean glass surface, and continuing this process for several hours (Fig. 1).

* Hovestadt, "Jena Glass."

In general the conclusion has been reached that films are more likely to form on surfaces enclosing the smaller spaces in an instrument. In binoculars deposits are found in the following approximate order of frequency.

- (1) Graticules.
- (2) Field lenses of eyepieces.
- (3) Prisms.

No case has been brought to our notice in which a deposit has been found on the object glass, although we have noticed one on the front window of a German Dial Sight.

It may also be mentioned that decomposition or clouding sometimes sets in in the narrow separating space between the two components of a non-cemented telescope objective. The action is said to be confined to the crown lens, and, as this is generally the exterior lens and most exposed to temperature changes, the action is possibly due to that cause. The cause of the more rapid deposition in smaller spaces is a matter which at present lacks satisfactory explanation. No explanation can be considered complete which does not make clear the general lack of permanent deposit on the objective. It is quite true that a short time ago most English graticules and eyepiece lenses were made from crown glasses, which are notoriously liable to the attacks of moisture; this might contrast with the flint surface of the objective, but apparently the trouble has not been completely overcome, though it has been lessened by the substitution of light flint glass for crown in the graticules. It may be noted that a glass frequently used for graticules by a German firm is Jena O463 Baryta Light Flint; with this glass no "film" has been noticed.

Whatever the exact cause of the deposition, it is evident that it must consist of material either

- (1) issuing from the glass,
- or (2) deposited from the air.

It has been conclusively shown that it consists of something other than water alone, such for example as a hygroscopic alkaline solution, oily or greasy material, or water drops covered with a film of grease sufficiently thick to retard evaporation. If the material issued from the glass it would almost certainly consist chiefly of water which had been forced into the glass during grinding and polishing operations. Such water would of course form an alkaline solution. It is well known that certain glasses (notably fluor crown) when freshly polished have mechanically unstable surfaces; the possibility of the absorption of some water in the outer layer is certainly a factor to be considered. It was arranged therefore that tests should be made on a freshly polished surface in the course of the work described in Section II.

Secondly, if the material has been deposited from the air it must be of some such nature as suggested above; in fact the most probable constitution of the deposit is that of drops of alkaline solution produced by the action of water on the glass, together with a coating of greasy material which has been derived from traces of grease remaining on the glass through defective cleaning, or from the

vapour of the internal lubricant in the instrument. Let us trace out the possible processes in the formation of such a film. The glass surface is possibly left, after cleaning, with traces of grease on it which are too small to be seen or detected. The surface, apparently smooth, is in reality very uneven, although the irregularities and pits are comparable with the wave-length of light. In addition, the air is full of dust nuclei of varying sizes, although in some cases the larger particles will have been removed by filtration. A certain number of these nuclei remain on the glass surface. Further, suppose the air becomes saturated with water vapour; water deposits wherever possible in small cavities or around the dust particles, which may have stuck more frequently to sleeks and traces of grease on the surface. With the water comes down a certain amount of the grease vapour present in the interior of the instrument. This, together with any grease on the glass, spreads by capillary action over the water surface and tends to retard evaporation. Where water, possibly contaminated with traces of acids, gets into contact with the glass surface a marked chemical reaction sets in and alkali is dissolved out from the surface. The action is enormously expedited with increase of temperature. It seems probable that the fatty acids of some lubricants may assist such reactions just as do the stronger inorganic acids. In one case described to us an air blast, which was not altogether free from traces of the pump oil, was used in the cleaning of graticules. The tendency to the subsequent formation of deposits was very marked and a great advantage was derived from the subsequent use of cleaner air.

From this point of view we may review the use of lubricants in optical instruments. Desirable features in a lubricant are:

- (1) It should contain no acid liable to attack the metal of the instrument.
- (2) It should be non-volatile.
- (3) It should be "sticky" or not readily squeezed out from between metal surfaces, and not be too sensitive to temperature.
- (4) It should not "gum" or dry on the surface.
- (5) It should not require too large or too small a starting force in the particular motion where it is employed.
- (6) It should be free from water.

Quite a number of lubricants are in common use, and experiments have been made to test the relative behaviour of certain specimens. Preliminary trials were made with a view to testing both spectroscopically and by a low temperature distillation process the relative volatility of these at ordinary temperatures, since it has been shown that the nature of the lubricant employed may have important effects in connection with "filming." The tests, however, proved very difficult to make satisfactorily and they have been deferred for the present, more direct tests being made. A few remarks, however, may be made on vaseline and mineral jellies. In the commercial form these may contain a considerable proportion of water which has to be removed before use. Dr Tinkler informs us that under certain conditions reactions with brass may take place, volatile fatty acids being formed. Such greases are, however, with this exception very stable and do not

oxidise. The commercial products are liable to contain traces of free mineral acid which should be looked for in fresh samples. As is well known an efficient lubricant is made by evaporating the more volatile constituents of mineral oil and dissolving pure rubber in it till the mixture is of the correct consistency. Such a grease is very useful as it possesses a greater stickiness than ordinary greases, and does not gum. Mineral jellies and most solid greases evaporate very slowly at ordinary temperatures.

To sum up the results of outside information, it seems probable that:

- (1) Deposits are in some way connected with the instability of glass surfaces.
- (2) The presence of oily vapours tends to facilitate the process.
- (3) Deposition occurs more readily in the smaller spaces of an instrument.
- (4) Careful cleaning, by means of which traces of fatty acids derived from the fingers, etc. are eliminated from the glass, is of great importance.

In some respects the results of the experiments to be described do not confirm the conclusions set out above.

It may be noted that the state of cleanliness of a glass surface even after careful cleaning is a very doubtful quantity. Lord Rayleigh has shown that the elliptical polarisation of light reflected from water surfaces is due to the presence of very thin grease films, and the average sample of distilled water is distinctly greasy. Even when alcohol and acetic acid are used for cleaning, traces may remain.

SECTION II. EXPERIMENTS PERFORMED.

PRELIMINARY EXPERIMENTS, ETC.

1. In the first place it was decided to make microphotographs of a number of deposits or "films" as they actually occur in instruments. This was done in order to obtain some information as to whether more than one type of deposit occurs, and to obtain some knowledge of the usual characteristics of the types met with.

2. *Types of globular deposit.*

The specimens photographed appeared to fall into several recognisable classes or types.

- (a) Deposit apparently composed of spherical and distinct globules. This type of deposit was mainly characteristic of the etched sides of graticules (Figs. 2 and 3).
- (b) Those in which the globules have run together or are slightly spread over the surface. Alignment is very marked in this type, which is characteristic of the non-etched sides of graticules.
- (c) A unique type with confused alignment noted in one case only.
- (d) Another unique class of deposit as previously mentioned was shown by a graticule which had not been in an instrument, but had been stored in an envelope after etching. The globules forming the deposit were unusually small and the "film" was unique in that it did not avoid the vicinity of the graticule lines.



Fig. 2. Graticule from Prism Binocular.



Fig. 3. Graticule from Prism Binocular. Etched side. Note clear space round graticule line.

3. Suggested causes of "filming."

It has been suggested that the deposits might be due to:

- (1) imperfect cleaning of the glass surfaces,
- (2) treatment of the glass previous to its being mounted in the instrument,
- (3) the effect of moisture in the instrument, especially in conjunction with heat,
- (4) the effect of lubricants enclosed in the instrument,
- (5) the nature of the glass,
- (6) the effect of residual traces of bronzing solutions or pickling acids.

To test the effects of the various suggested causes of filming a number of experimental brass cells were made.

4. Description and dimensions of cells.

The cells consisted of short cylindrical brass tubes closed at each end by a glass plate. Thickness of cell from glass plate to glass plate .5 cm.-1 cm. (the majority were 1 cm.). Diameter 1.6-4.1 cms. The glass plates used in these experiments were blank or rejected graticules.

EXPERIMENTS AND RESULTS.

Note. In the tables of results given the word "film" is intended to denote an appearance similar to that of the globular deposits described in Paragraph 2.

Where definite disintegration of the surface has been observed it is described as such.

Cleaning of glass.

A cell was set up in which the only difference between the inner surfaces of the two plates of glass was the mode in which they had been cleaned. Surface (7) was cleaned with

Ammonia,
Distilled water,
Nitric acid,
Distilled water,

Caustic soda,
Distilled water,
Methylated spirits.

It was:

- (1) rubbed with a silk rubber, one side of which had been carefully kept from contact with the fingers,
- (2) dusted with a clean brush that had been dipped in ether and dried, and then
- (3) dust-free air was blown over the surface for a few seconds.

This method of cleaning will in future be described as method *A*.

Surface (8) was cleaned with methylated spirits and rubbed with a silk rubber, both sides of which were fingered alike. This method of cleaning will in future be described as method *B*.

Treatment of cell after being set up.

The cell was placed in an ice box every night in order to cause condensation on the interior glass surfaces, and taken out every morning. This process was continued for 28 days. During this period the surfaces were microscopically examined at intervals.

Result. Very little change was observable on either surface. On (7) there were a few groups of dots, possibly minute pits in the glass, but the effect was small. The cell was then placed in an oven heated to about 34° C. by an electric lamp, and alternately heated to this temperature, and allowed to cool once daily.

Result. (7) developed a number of apparently minute pits,

(8) developed a very few pits, mainly concentrated on one region.

In both cases the effect was small.

Surface	Method of cleaning	Ice box 25 days	Ice box 28 days	Oven 34 days
7	<i>A</i>	No change	Groups of small pits	Surface dotted with pits
8	<i>B</i>	No change	Little effect	Very few pits

This table shows no certain difference produced by the method of cleaning.

Previous treatment of glass surfaces.

To test the effect of the previous treatment of the glass surfaces 3 cells were set up:

Optical xx

(a) Cell (1, 2).

Surface 1 was placed for about 2 hours in strong sulphuric acid and then cleaned by method B.

Surface 2 was boiled in water and then cleaned by method B.

(b) Cell (3, 4).

Surface 3 was freshly polished with rouge on pitch and cleaned by method B.

Surface 4 cleaned by method B.

(c) Cell (13, 14).

Surface 13 was heated to 200° C. for 1½ hours and cleaned by method A.

Surface 14 was boiled in grease (belmoline) and cleaned by method A.

Treatment of cells.

Ice box for 31 days for (1, 2) and (3, 4).

" " 16 " (13, 14).

Oven at 34° C. for 34 days.

Results.

Surface	Treatment of surface	Method of cleaning	Ice box		Oven 34° C.	
			16 days	31 days	50 days	60 days
1	H ₂ SO ₄	B	No change	No change	Surface slightly pitted	Some very fine pits or film
2	Boiled in water	B	"	"	A few pits	A few pits
3	Polished rouge	B	"	"	No change	Practically no change
4	—	B	"	"	Surface affected in one place	Considerable disintegration in one place
13	Heated to 200° C.	A	Almost clear	—	30 days A few holes	51 days Small patches of disintegration
14	Boiled in grease	A	No change	—	Nothing	A few pits and some patches of disintegration

These results are mainly negative.

Effect of moist air and heat.

To test the effect of moist warm air 4 cells were set up, viz. (25, 26), (27, 28), (29, 30), (31, 32).

(a) Cell (25, 26).

Surface 25 was cleaned by method A.

" 26 " " " B.

(b) Cell (27, 28).

Both surfaces were boiled in water before being mounted in the brass cell.

Surface 27 was cleaned by method A.

" 28 " " " B.

(c) Cell (29, 30).

Before the glass plates were put in, the brass cell was steeped in strong hydrochloric acid for 2 hours, then washed and dried. This was done to test the possible effect of any residual vapours from pickling acids.

Surface 29 was cleaned by method *A*.

" 30 " " " *B*.

(d) Cell (31, 32).

The interior of the cell was bronzed with arsenical bronzing solution and afterwards carefully cleaned by washing.

Surface 31 was cleaned by method *A*.

" 32 " " " *B*.

Treatment of cells.

The cells were kept in air saturated with water vapour in an oven heated by an electric lamp to 34° C.

Results.

Previous treatment	Method of cleaning	Surface	After 1 day	5 days	25 days	48 days
Nil	<i>A</i>	25	Some dots	Much pitted	Badly disintegrated	Heavy decomposition of surface
	<i>B</i>	26	"	"	Badly disintegrated, not so much as 25	Considerable surface disintegration
Glass boiled in water	<i>A</i>	27	Surface attacked in one place	Very little effect	Very little effect	Very little effect
	<i>B</i>	28	A few dots	Very little effect	Surface affected at edge	Considerable disintegration
Brass cell steeped in strong HCl	<i>A</i>	29	Very little effect	Fine film	Considerable film	Great deal of disintegration
	<i>B</i>	30	Very little effect	"	" "	Considerable disintegration
Interior of cell bronzed	<i>A</i>	31	Signs of film	Film edge near	Film	Considerable disintegration
	<i>B</i>	32	Less than 31	Considerable film	Surface disintegration	Heavy disintegration

The effect of moist air and heat in producing disintegration is clearly shown. The effect of a previous boiling in distilled water in delaying the action should be specially noted. Some of the effects obtained are illustrated in Figs. 4-7.

Effect of lubricants.

A number of cells were set up. One surface of each cell was cleaned by method *A*, the other by method *B*. In each cell a small quantity of some kind of lubricant was introduced. The lubricants experimented with were: vaseline, belmoline, clock oil and a commercial grease (*A*).

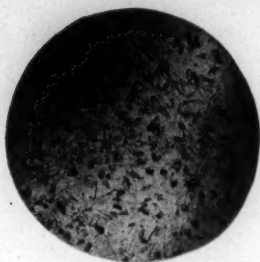


Fig. 4. Surface 25 after 48 days.



Fig. 5. Surface 26 after 48 days.

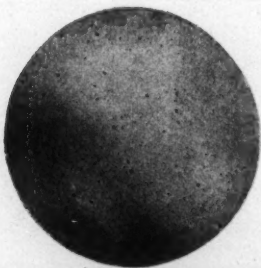


Fig. 6. Surface 28 after 48 days.
(Glass previously boiled in distilled water.)

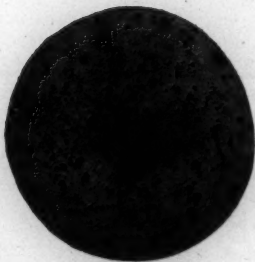


Fig. 7. Surface 32 after 48 days.

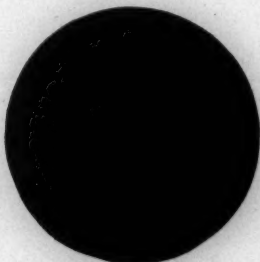


Fig. 8. Surface 11.
Globular film from Vaseline.

Treatment of cells.

At first they were placed every night in the ice box. Later they were placed in the oven at 34° C.

Results.

	Surface	Method of cleaning	Ice box			Oven			
			9 days	10 days	27 days	32 days	43 days	51 days	62 days
Vaseline	11	A	—	Decided film	Film	—	Film	Film	Great deal of film
	10	B	—	Decided film	Heavy film	—	Film	Film	Great deal of film
Belmo-line: Glass: Optical plate	17	A	—	Slight film	Film in one place	Considerable film in one place	Considerable film in one place	—	Considerable fine film
	18	B	—	Slight traces of film	Very little effect	Very little effect	Very little effect	—	Very little effect
Clock oil	21	A	Some globules	Signs of film	—	Some film	—	Considerable film	—
	22	B	Very little film	Some film	—	Some film	—	Considerable film	—
Specimen A	23	A	No change	No change	—	No film	—	Some small dots and pits	—
	24	B	No change	No change	—	No film	—	Some small dots and pits	—

The effect of lubricants in producing globular deposits is clearly indicated. The effect obtained with vaseline is shown in Fig. 8. The table also shows that lubricants differ in the rapidity of their action. Subsequent experiments deal more fully with this point.

*Kinds of glass.**A. Effect in dry air.*

A cell was set up (15, 16).

Surface 15 was of Ba. Cr. glass.

" 16 " H.F. "

Both surfaces were cleaned by method A.

Treatment of cell.

Ice chest every night for 28 days.

Oven at 34° C. every night for 34 days.

Result. Throughout the time there was no observable effect on either surface.

B. Effect in moist air.

The following cells were used:

- (1) Cell (7, 8) was a cell of the former series.
- (2) Cell (15, 16) was a cell of the former series.
- (3) Cell (19, 20) was freshly set up.
Glass: Optical plate. Cleaned by method *B*.
- (4) Cell (33, 34) was freshly set up.
Glass: Barium Light Flint.
Brass cell. .5 cm. long.
Cleaned by method *B*.
- (5) Cell (35, 36). Freshly set up.
Glass: Barium Light Flint.
Brass cell. 4 cms. long.
Cleaned by method *B*.

Treatment of cells.

The cells were put in moist warm air in the oven for 12 days.

Results.

Glass	Surface	Method of cleaning	12 days	35 days
Cr.	7	<i>A</i>	Definite disintegration	Considerable uneven disintegration
Cr.	8	<i>B</i>	Little effect	Some disintegration
Ba. Cr.	15	<i>A</i>	Disintegration in form of minute pits	Action continued
H.F.	16	<i>A</i>	Disintegration. Minute pits	" "
Opt. plate	19	<i>B</i>	Surfaces beginning to disintegrate	Action continued
Opt. plate	20	<i>B</i>	Little effect	Definite disintegration
B.L.F.	33	<i>B</i>	Surface covered with pits	Action continued
B.L.F.	34	<i>B</i> cell .5 cm. long	Covered with small pits	" "
B.L.F.	35	<i>B</i>	Some disintegration	" "
B.L.F.	36	<i>B</i> cell 4 cms. long	Fewer pits but larger and more irregular	" "

The results of these attempts to differentiate between different kinds of glasses in the rapidity of their action in forming visible pits are negative.

Effect of bronzing solution.

A cell was set up. Cell (9, 12).

Surface 9 was cleaned by method *A*.

" 12 " " " " *B*.

The interior of the cell was bronzed with arsenical bronzing solution. The bronzing was allowed to dry, but no effort was made to clean off any traces of solution that might remain.

Treatment of cell.

Ice box every night for 28 days, oven for 34 days.

Result. A characteristic film appeared within one day. This film continued to increase during the remainder of the time that it was under observation.

EXPERIMENTS WITH LUBRICANTS.

In order to test further the effect of various lubricants, it was decided to make a series of brass boxes, each having a glass window. The under surface of this glass plate could be exposed to the effect of the vapours of the lubricants and the lid could be removed in order to examine this under surface.

Description of boxes used.

The boxes used were cylindrical in shape, and made of brass, 1.5 cms. deep and of 1.9 cms. radius. A glass graticule (0.9 cm. in radius) was bezzelled into the lid. The lid was fairly tight fitting. Various lubricants were placed within the boxes as shown in the following table. The glass plates were cleaned by method *B*.

Treatment of boxes.

The boxes were set up and placed in an oven at 34° C. for 41 days. They were then opened and the glass surfaces examined. No effect was observed on any of the boxes. The glass plates were then again cleaned by method *B* and examined under the microscope in order that their appearance and cleanliness might be certainly known. A drop of distilled water was then placed in each box, in addition to any lubricant that might be already there. The boxes were then again closed and placed in the oven for 15 days. They were then again examined; another drop of water was enclosed in each and the box replaced in the oven. Seven days later the examination and the addition of the water were repeated.

In the acid test column the figures express the number of grammes of NaOH required to neutralise 1 gramme of the lubricant. Note that the glass cleaned with alcohol has shown by far the most visible disintegration.

Reference was made in the introduction to this paper to certain well-marked differences exhibited by certain glasses with regard to their chemical stability and hygroscopic nature; a summary of evidence on this point may be usefully given. As will be seen, the quicker tests are made under somewhat artificial conditions and their results are apparently not always in agreement. For the sake of comparison we may quote the results of Kohlrausch for "solubility" given in "Jena

Results.

No.	Glass	Lubricant, etc.	Acid test	Dry air 41 days	Moist air		Effect on brass of cell
					15 days	21 days	
1	Cr.	Vaseline	Negligible	No effect	Some globules especially near edge	Globular film. Some pits	Nil
2	Cr.	Belmoline	"	"	Irregular shaped deposit like crystals	Globular film	Nil
3	L.F.	Vaseline	"	"	Some globules	"	Nil
4	L.F.	Belmoline	"	"	Considerable number of globules	Considerable number of globules	Nil
5	L.F.	Clock oil	"	"	Fine globules	Some globules and pits	Black spots on brass
6	L.F.	Specimen A	.0028	"	A few globules	A few globules. Several pits	Grease has turned green
7	L.F.	Lanoline	.01	"	Signs of fine globules	A very few globules and pits	Lanoline turned green and gummed
8	L.F.	German vaseline	—	"	A few globules	A few pits. Very few globules	Nil
9	L.F.	Specimen B	.007	"	Considerable and rather smeary film	Considerable film. Heaviest in the series	Grease turned a little green
10	L.F.	Empty	—	"	Clear	One or two pits, almost clear	Nil
11	L.F.	Specimen C	Negligible	"	Very little	Very few globules	Nil
12	L.F.	Empty glass cleaned with alcohol	—	"	Few pits otherwise clear	Considerable glass disintegration	Nil

Glass." These results place the glasses mentioned in the following order, beginning with the glasses least susceptible to attack.

Name	Jena No.	Name	Jena No.
1. Densest Flint	S 164	9. Crown	283
2. Very Dense Flint	303	10. Borosilicate	599
3. Zinc Barium Crown	227	11. Potash glass (Bohemian)	
4. Densest Barium Crown	634	12. Light Phosphate Crown	O 225
5. Ordinary Flint	824	13. Crown	260
6. Barium Crown	227	14. Baryta Crown	861
7. Light Flint	677	15. Borate Flint like S 8	
8. Thermometer glass		16. Potash Crown	365

A further test employed widely has been the autoclave test, in which glass specimens have been kept in superheated steam under a pressure of two or three atmospheres for several hours. As the result of one test on a series of Messrs Chance's glasses the relative susceptibility to attack under these conditions appeared to place the glasses in the order given, starting with those least affected.

Name	Chance's melting No.	Name	Chance's melting No.
1. Dense Barium Crown	3862	5. Heavy Flint	4193
2. Extra Light Flint	3687	6. Medium Barium Crown	4157
3. Hard Crown	4183	7. Borosilicate Crown	4181
4. Baryta Light Flint	773	8. Telescope Flint	4277

The specimens from the National Physical Laboratory, which were recently exhibited at the Optical Society*, are of interest in this connection. Five samples were exhibited which the iodeosin test had placed in the following order.

1. Medium Barium Crown	} Approximately equal
2. " " "	
3. Extra Dense Flint	
4. Double Extra Dense Flint	
5. Glass "H ₅ "	Decidedly inferior

For nearly two years the specimens had been exposed to the weather. The order of liability to surface tarnish after this is found to be, commencing with the cleanest glass:

1. Glass "H ₅ "	} Approximately equal
2. Extra Dense Flint	
3. Medium Barium Crown	
4. Double Extra Dense Flint	
5. Medium Barium Crown	

More complete results as to the indications of the iodeosin test are required, but we understand there is a probability of their availability in the near future.

The decided action of the vapour of arsenical bronzing solution in forming globular deposits has been investigated by us in the case of a representative series of English glasses; the result may be given in the order of intensity of action or deposit on the surface. The differences in action on the various glasses were very marked, there being a regular gradation from the Heavy Flint which was little attacked to the Fluor Crown which was heavily encrusted.

1. Heavy Flint	3244	} About equal	7. Extra Dense Flint	3345
2. Boro. silic. Crown	3227		8. Medium Barium Crown	3225
3. Hard Crown	3118		9. Double Extra Dense Flint	2922
4. R. Light Flint	2731		10. Baryta Light Flint	3060
5. Baryta Light Flint	2952		11. Dense Barium Crown	2871
6. Heavy Flint	3063		12. Soft Crown	2987
			13. Fluor Crown	3247

It was thought that possibly the action of the bronzing solution might afford some indication of the relative stability of the glasses but unfortunately there is no precise agreement between these various lists. It may be pointed out, however, that the most striking difference in the "open weathering" test from the results of the iodeosin test (i.e. the good behaviour of the "H₅" glass) does not show that it is less soluble, or that it would behave better when enclosed in an instrument. The glass is probably of such a uniform texture that the polish of the surface is apparently unchanged by the solution of the surface layers, while the Medium

* W. H. Withey, *Trans. Opt. Soc.* 20 (1918), 40.

Barium Crown becomes extremely rough. For example, in the tests made with bronzing solution vapour a crust or efflorescence is formed on the glass surfaces which in most cases can be scraped away, leaving a comparatively polished surface. In considering the lack of indication, in the experiments described in the present paper, of recognisable differences in the rapidity of the formation of visible surface pitting (with various glasses) under the attacks of moisture, it must be remembered that the amount of visible effect may not be a true indication of the actual amount of chemical action which has taken place in the surface. We may therefore be forced to consider that the tables of Kohlrausch can give no true indication of the relative speed of surface deterioration as far as optical polish is concerned. Some indications go to show that comparatively slight changes in the composition of a glass may make considerable differences in its chemical stability.

SECTION III. CONCLUSIONS.

(a) The method of cleaning has not been shown to produce any difference, when reasonable precautions are taken in the cleaning.

(b) Effect of treatment of the surfaces previous to cleaning. The surfaces boiled in distilled water have been shown to withstand the attacks of moisture on the whole better than surfaces otherwise treated.

(c) The results appear to show that moisture alone will quickly produce disintegration, the action rapidly increasing with the temperature, but that moisture alone has no effect in producing the globular deposit.

(d) The presence of lubricants does not produce globular deposit nor disintegration of surfaces unless moisture is also present. The following table gives a list of a number of lubricants arranged in order according to the cleanliness of the glass surfaces exposed to their vapours—moisture also being present. Specimens *A*, *B* and *C* were specimens of commercial greases used in the optical industry.

- | | |
|------------------------|------------------------|
| 1. Specimen <i>C</i> . | 5. Clock oil. |
| 2. German vaseline. | 6. Belmoline. |
| 3. Lanoline. | 7. Vaseline. |
| 4. Specimen <i>A</i> . | 8. Specimen <i>B</i> . |

(e) In the case of the glasses with which we have experimented, namely H.F., L.F., B.C., Ordinary Crown and Optical Plate, we have not detected any difference in the rate of commencement of disintegration due to the kind of glass used, and in the case of Ordinary Crown and L.F. we have not detected any difference in the rate of formation of globular deposits.

(f) The relative size of the cells has apparently made no difference in the rate of formation of visible pitting.

In so far as these conclusions admit of practical application in the construction of optical instruments, they point to the need for the instruments to be filled carefully with dry air and if possible made airtight, and indicate that great care should

be used in the selection of the lubricant. The boiling of glass surfaces in distilled water is a point well worth the consideration of manufacturers. Such boiling should not be too prolonged, as otherwise the polish of the surface may be affected.

In conclusion we should like to express our indebtedness to the D.I.O.S., Woolwich and to Messrs Barr & Stroud, Messrs R. & J. Beck, Messrs Ross, Ltd., and Messrs Chance Brothers & Co., Ltd., for the loan of specimens, to Mr Morrison and Dr Tinkler for the benefit of their experience, to Messrs Ottway for many practical details, to Mr Julius Rheinberg and Messrs Sherwood for generous advice and assistance, and finally to the authorities of the National Physical Laboratory for permission to describe certain experiments on the weathering of glass.

DISCUSSION

Lieut.-Col. A. C. Williams thought that any experiments of the kind the authors had dealt with were useful. The more results on the subject one could obtain, the better.

Mr H. A. Hughes did not think that the results obtained with moisture would apply to any of the difficulties that had been met with at Woolwich. He would like to know if it made a great difference to have the assembling rooms dry.

He had always thought that the question of blacks and bronzing solutions was an important one.

He asked whether the authors had tried cells made of such substances as aluminium alloys and ebonite.

Mr Julius Rheinberg said he was glad to find in the paper corroboration of his own conclusions that filming was not in the great majority of cases due to the glass employed, but to other causes.

He thought that the elaborate chemical method (A) of cleaning described might easily have led to heterogeneous deposits on the glass and have been less effective than the simpler method (B).

In the case of a specimen boiled in grease, the whole surface might have been impregnated with an even deposit less injurious than uneven deposits.

He asked if the final cleaning was with ordinary methylated spirits containing traces of mineral oils, or with industrial spirits.

Mr P. F. Everitt wished to know if the silk rubber had been carefully cleaned before being used.

In the case of glasses polished with rouge no mention had been made as to whether a cloth, wax, or pitch polisher had been employed.

He noticed that only one or two crown glasses had been experimented with; there is quite a variety of crowns having widely different chemical constitutions. In one series of experiments no light flint glasses had been tested.

He asked whether cells made of different kinds of brass had been used.

Mr T. Smith thought that the authors' work was of a preliminary nature and that none of the results could yet be taken as conclusively established. Film appeared in only a proportion of cases though the conditions in all seemed to be identical. The experiments should be repeated with 50 or more specimens of each glass, say 5 each from 20 different meltings of glass of the same composition. Experiments on such a scale seemed essential in dealing with a problem of this character.

In the case of the National Physical Laboratory specimens two pairs of glasses, which had identical optical properties and gave identical results with the iodeosin test, had given quite different results with the weathering test. One possible explanation was that there may be differences in the specimens if one could examine them on a microscopic or an ultramicroscopic scale. The inference must be drawn that the examination of single specimens of glass or of single meltings might lead to conclusions which would not hold for all glasses of identical composition.

Mr S. D. Chalmers considered that the authors had obtained one valuable definite result, namely, that moisture and grease were required for the production of film. It would be interesting to find out whether any other volatile substance than water would produce the same effect.

It was important not to judge the chemical tests only by the depth of the colour obtained. Dr Rosenhain had shown that very slight tints sometimes indicated great chemical instability.

In such experiments as the authors had tried one was very apt to consider only one kind of film and to draw conclusions accordingly, whereas different manufacturers seemed to have trouble with different types of films. It was important, therefore, to test specimens from all possible sources.

Mr H. S. Ryland drew attention to the results shown in the table on p. 143, where good results were obtained by boiling the glass in distilled water; also when the surface was cleaned with silk which had been fingered, the result was not good. He suggested that a series of experiments should now be carried out in which the surfaces were cleaned after boiling in water. Sometimes boiling would produce a number of fine cracks over the whole of a surface. Where this is the case hot, but not boiling, water may be used. One firm which had adopted the recommendation given in his (Mr Ryland's) paper, say that their film or scum trouble has practically ceased.

He described an experiment which he had tried. He had taken a cell, having two small apertures for the passage of air, containing a specimen surface. When the surface was prepared by the hot water treatment, damp air would cause a deposit which could be completely cleared by heating. If the entrant aperture were lined with grease and damp air passed through, the deposit could not be completely cleared by heat although it was slight. When, however, the surface was just wiped in the ordinary way, the deposit could not be cleared by heat even when the entrant aperture was clean. If it were lined with grease the deposit was rather more dense and could not be cleared by heat.

Mr A. V. Elsdon said that he had been carrying out experiments on filming at Woolwich, from the point of view of the stability of the glass, which was undoubtedly one of the factors to be considered. One of the tests employed was the "dimming" test, an elaboration of that originally proposed by Zschimmer. It consisted in passing a current of air, saturated with water vapour, over glass surfaces for a definite time at a definite temperature, and noting the effect on the glass. The air was filtered to remove dust particles and the glass was carefully cleaned before the test. Plates of polished quartz or silica glass were used as controls.

He had tried to make the test semi-quantitative by dividing the glasses into three classes according to the degree to which they were affected, as determined by careful visual and microscopical examination. There were very great differences in the behaviour of different glasses but he was not yet in a position to draw any definite conclusions from the results.

The iodeosin test was also in use. In this case the precise manner in which the test was carried out was very important. At the Directorate of Chemical Inspection, iodeosin tests were always made in triplicate when possible, both on a freshly broken surface and on a similar surface after "weathering" in moist air for seven days at a temperature of 18° C. There was undoubtedly some relation between the behaviour of a glass in the "dimming" test and the iodeosin test on a weathered surface, as carried out at Woolwich, although the results of the two tests were not always parallel.

He could confirm the result obtained by the National Physical Laboratory as to the variation in behaviour of different specimens of glass of practically identical percentage chemical composition and was inclined to attribute this to difference in molecular constitution.

He would be glad if the authors could give some information with regard to the greases employed in their tests, especially that of the German vaseline which behaved so much better than ordinary vaseline.

The President (Prof. Cheshire) considered that the question of polish was very important. Prof. Carpenter had told him that rustless steel depended for its property on the state of polish; if it became scratched it would rust.

The problem of filming was not likely to be solved except by regular research attack. He thought that the authors had made a beginning in such an attack, and that some of the results were very valuable.

Mr Martin, in reply to Mr Hughes, said that the work had been undertaken because the problem was an obscure and pressing one. The results on the effect of moisture, he thought, were valuable in connection with the use of optical instruments employed in tropical countries.

They had not tested the effects of blacks because they considered that Mr Ryland's results on that subject were conclusive. They had not had time to test cells made of any substance other than brass.

In the chemical method of cleaning, he agreed that traces of impurities might

get into the surface, as suggested by Mr Rheinberg, and render it more liable to film. Industrial spirits had been used in the experiments.

Replying to Mr Everitt, he said that the rouge polishing had been done with a pitch polisher. Cleaning cloths had been carefully washed and dried before use.

No light flints had been employed in one series of experiments, because they had been unable to obtain L.F. graticules in time for this part of the work.

The brass used for the cells had been obtained from one firm, and was presumably alike throughout all the tests.

In reply to Mr Smith he admitted that the work was introductory, but it was only by carrying out preliminary experiments that one could show the necessity of carrying out experiments on a large scale. He thought that some of the general results obtained could be taken as conclusive.

They had not proved that the method of cleaning was not important, but only that there was no general agreement in the results obtained from altering the methods of cleaning.

He thanked Mr Elsdon for the particulars of the dimming test. He did not know in what way the Germans had treated the vaseline.

With reference to the N.P.L. specimens he considered that the state of polish does not necessarily throw any light on the amount of chemical action which may have taken place on the surface.

OBSERVATIONS ON THE EFFECTS OF TREATING GLASS SURFACES WITH CERTAIN LUBRICANTS, AND THE TEMPERATURES AT WHICH OBSCURATION TAKES PLACE

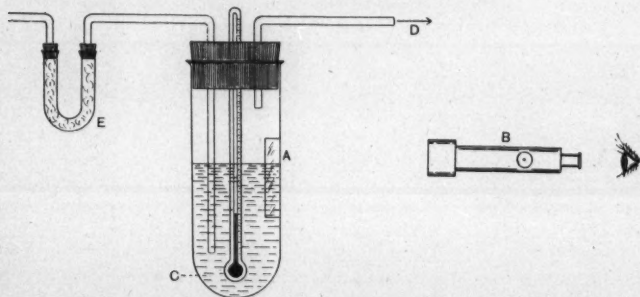
By WM SHACKLETON, A.R.C.Sc.

Read, 13th February, 1919

FOR many years prior to the war it had been customary to supply certain masks fitted with goggles and used in surgical operations with a lubricant mounted in the form of a pencil which when rubbed on the goggles and gently polished with linen prevented the glasses steaming during an operation. During the war the need for some such preventive became acute as the interior of telescopes steamed to such an extent that they were useless under certain low temperatures.

Below are given the results of some observations of the application of three lubricants on glass surfaces. The three lubricants tried were: Lasin (the one referred to above), "Everclear," a paste put up in a collapsible tube, and "Nephelless," a preparation of my own, of which more in due course. There is another preparation which I have come across, "Clarocit," but have not tried as regards temperature though it answers its purpose much in the same way as the others.

The apparatus used in making the observations is as follows:



A Strip of Glass treated with lubricant. *B* Reading Telescope. *C* Ether. *D* Connection to Pump. *E* Drying Tube (without this Ether becomes cloudy below 0°C .).

All lubricants produced much the same result. As the temperature fell, the glass surface unlubricated became obscured and the thermometer could not be read through the deposit of dew, whilst the portion of the glass surface lubricated remained clear but became wet as the temperature fell a few degrees more. The

point at which steaming began was found to be the "dew point" and varied from time to time according to the "humidity" of the atmosphere. On continuing lowering the temperature the dew turned to hoar frost about 0°C . but still the lubricated portion remained transparent though very wet; reducing the temperature still further it was found that near -10°C . the lubricated portion became obscured in consequence of the liquid freezing, although the rest of the unlubricated surface had been a mass of ice for a long time.

A set of observations is recorded as follows:

	Lasin	Everclear	Nepheless
Temperature at start	17°C .	17°C .	17°C .
Obscuration of untreated surface	12	11	11
* Untreated surface freezes	-2	-1	-2
† Treated surface obscured	-6	-8	-10

Now, the last figures indicate that the low temperature is due to the "depression of the freezing-point" by the admixture to the water of condensation of some substance in the lubricant (in my case it is glycerine), and if some suitable substance can be obtained which will so alter the surface-tension and cause the glass to be wetted at the dew-point steaming will be prevented; this substance should not be hygroscopic as is glycerine (which is therefore not ideal) but it should be such as will not scratch glass easily and can readily be applied. In my opinion, however, such remedies are palliatives in the case of the internal parts of optical instruments, for while they may be of use externally, as on spectacles or on the mirror of a bath-room it would be more satisfactory if makers would ensure instruments being thoroughly dry and filled with dry air before leaving the workshop. It is true such remedies are found useful in kinemas, but the soft soap used by motorists to anoint their front screens in order to prevent steaming seems equally effective.

In conclusion I might say what my mixture consists of exactly and indicate its usefulness in another direction which may be of interest in view of the cold weather. The substance I have called "Nepheless" is made by adding to glycerine a quantity of sodium stearate; if sufficient sodium stearate be added (20 % or more), and the whole heated till dissolved and allowed to cool, a fairly hard leathery substance is formed † which may be mounted in wood as a pencil, but for a preparation required to be used from collapsible tubes, about 2 % of sodium stearate is all that is required; on cooling, this will be found to be a gelatinous mass which can be macerated into a white paste. If there is too much of it for use on glass, in this paste form, I can assure you it will be found a most useful application for the skin in case of roughness or chapped hands, and it is even said to be good for thilblains. Our chemists tell me they are known better for the issue of this mixture among the fair sex than for all the chemical work they do, and thus I am glad to know that this little piece of work achieved success in one way, if not exactly in the way intended.

* These readings are below zero, but it is difficult to say exactly when freezing takes place, and some results go as low as -4°C .

† These results were pretty constant and always in this order, but a slight variation of a few degrees was produced by the method or vigour in polishing.

‡ Sold I believe by chemists as solidified glycerine.

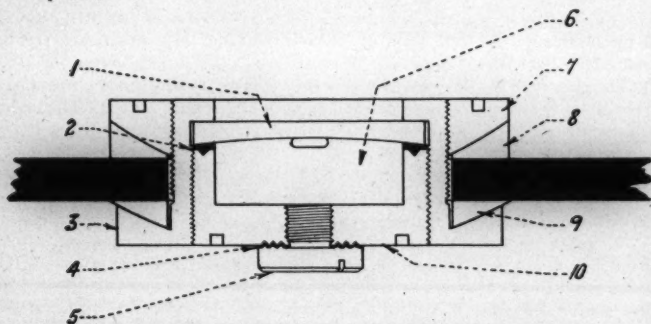
DESCRIPTION OF A GERMAN CIRCULAR SPIRIT LEVEL

By JAMES W. FRENCH, B.Sc.

Read, 13th February, 1919

STRAIGHT tubular spirit levels have the advantage that, when the level is heated, there can be no loss of the spirit, provided the temperature is not raised to such an extent as to increase the internal pressure unduly, as would be the case if the vapour bubble disappeared, in which case the tube might fracture. Spirit levels in which the spirit is contained in a metal holder and the bubble is viewed through a glass window suitably curved on the under side are not always free from this objection.

The following description of a circular spirit level taken from the compass of a Zeiss director may be of interest to the members of the Optical Society, as the design of level in question appears to be unaffected by considerable increases of temperature.



1. Window. Underside fine ground with 15 min. emery. Radius of curvature = 26 inches.
2. Lead Foil Washer. 3. Bubble Cell Holder. 4. Lead Foil Washer. 5. Screw. 6. Benzol.
7. Nut, spherical. 8. Washer, spherical. 9. Washer, spherical. 10. Bubble cell.

Section of Zeiss Circular Level.

The diagram shows the general arrangement. The spherical washers (8) and (9) and the nut (7) are provided for the adjustment of the spirit level as a whole relatively to the compass. Rotation of the bubble cell holder (3) relatively to the compass is prevented during adjustment by a small key not shown in the diagram. The window (1) is inserted in the bubble cell holder (3) and is retained in position

by the bubble cell (10). Between the cell (10) and the window there is provided a lead foil washer.

Benzol is inserted into the chamber of the bubble cell through a hole in the base which is finally closed by means of a screw (5). Between the under face of the screw head and the face of the bubble cell there is provided a lead foil washer. When the bubble cell is screwed hard home, the lead is squeezed into a "V" groove in the bubble cell and similar corrugations are provided between the screw (5) and the lower face of the bubble cell. It would appear that the tightness is due to the use of these lead foil washers.

The metal used is of the same brass composition throughout, but the exposed parts were nickel-plated. The analysis of the brass is as follows:

Tin	Nil
Lead	3.508 per cent.
Silicon iron	0.028 "
Manganese	Nil
Nickel	Nil
Copper	57.520 per cent.
Zinc	38.974 "
	100.030 "

The composition of the brass calls for no special remarks except that the purpose of the unusually large percentage of lead is presumably to improve the drawing or machining qualities.

The glass used for the window was of very ordinary quality, probably ordinary sheet glass. The upper surface did not appear to have been worked. The under surface was curved to a radius of 26". It was grey-ground, evidently with 15-minute emery.

The lead foil washers were .01" thick. The practical effect of the lead washer is to make a tight joint between the contiguous parts, due to the screwing up of the cell (10) or the screw (5) respectively.

As the level is heated the brass will expand more than the glass window, which would become slack in its seating. The ideal construction is one in which the arrangement of the materials is such that, as the level is heated, the differential expansion of the materials will be such that there is no slackening at the various joints. The coefficients of expansion of the materials are in the following ratios:

Drawn brass	0.19
Plate glass	0.09
Lead	0.29.

Compared with the other materials, the expansion of the glass is therefore negligible, and it will be seen that the lead has considerably greater expansion than the brass. But the thickness of the washer is only .01", whereas the width of the space into which the glass and lead fit is 0.07"; therefore in the design indicated there must be an actual slackening of the joint at the glass as the temperature is raised.

Notwithstanding this, a spirit level made to the same design has successfully withstood five temperature tests in which the temperature was raised to a maximum of 140° F., which was maintained in each case for thirty minutes.

The tightness of the spirit level would appear to be due solely to the malleability of the lead and the tightness with which the various parts are screwed together.

By a suitable choice of the material of the bubble cell and of the holder, together with a slight modification of the design, it should be possible to ensure an increase of pressure on the lead foil washer as the temperature is raised.

The level was found to contain benzol. The choice of a suitable liquid would appear to be determined by its viscosity and coefficient of expansion. A very viscous liquid would not respond to changes of level with sufficient rapidity and a liquid of high expansion would cause the bubble to disappear for a comparatively small increase of temperature and increase the pressure, tending to cause the escape of liquid.

It should be observed that the grey appearance of the ground glass will depend upon the refractive index of the spirit. A tube filled with ether will look greyer than when filled with benzol.

The expansions of various spirits are in the following ratios:

Benzol	1·176
Ethyl alcohol	1·041
Ether	1·513
Carbon disulphide	1·140

It will be seen that, so far as expansion is concerned, benzol should give considerably better results than ether, that it is somewhat worse than ethyl alcohol, and about the same as carbon disulphide.

The viscosities of the various spirits are in the following ratios, the viscosities being measured at 20° C.:

Benzol	·006
Ethyl alcohol	·012
Ether	·002
Carbon disulphide	·004

Whereas benzol is worse than alcohol as regards expansion, it is twice as good as alcohol as regards viscosity, that is, from the point of view of a bubble. It is worse than ether as regards viscosity but, as already stated, it is much better than ether as regards expansion. Benzol is worse than carbon disulphide as regards viscosity and, as stated before, about the same as regards expansion. It must be borne in mind, however, that a certain amount of viscosity in the liquid may be desirable, the amount depending upon the purpose for which the level is required. On the whole, therefore, it would appear in this particular case that the choice of benzol as a spirit level liquid is a good one. The spirit appeared to be 90 % benzol.

ABSTRACTS

"On the Theory of Surface Layers." By H. SCHULZ, *Verhandl. d. Deutsch. Physikal. Gesellsch.* 18 (1916), 384.

If plane-polarised light falls on an isotropic medium the reflected light should, according to Fresnel's formulae, also be plane-polarised, but actually it is elliptically polarised. This is usually explained by the assumption that between two isotropic media one has to deal with a transition layer, the thickness of which is small in comparison with the wave-length of light. This layer, according to Drude, is due to adhesion, and possesses the property of continuous variation of refractive index. In addition there is frequently a surface layer, as in the case of glass, due to the polishing material, which strengthens the natural surface layer. The author upholds Kynast's theory, according to which the surface layer has a crystalline structure arising from a pressure, caused by the molecular forces of the glass, acting on the layer in a direction perpendicular to the surface; the layer thus behaves like a uniaxial crystal. The outermost layers of a homogeneous isotropic body may therefore be looked on as doubly refracting.

The problem is treated mathematically, use being made of Neumann's formulae, and the results are compared with the observations of Pockels. The effect of external pressure is also considered. If the pressure is not uniform, the surface layer will exhibit a different distribution of pressure from the interior of the body; the pressure will diminish towards the outside. It is found that for low indices of refraction the pressure perpendicular or parallel to the plane of incidence in the neighbourhood of the polarising angle affects the original ellipticity present in the opposite sense. For $\mu = 1.88$ the effect of pressure is independent of the direction of the pressure. Further investigation is required, as not sufficient data are at present available.

J. S. A.

"On the Grain of the Photographic Plate, and a Method of investigating it." By P. P. KOCH and G. FREIHERR DU PREL, *Phys. Zeitschr.* 17 (1916), 536.

As the silver bromide grains of a photographic plate are only a few thousandths of a millimetre in diameter, microphotographs giving a magnification of 100 to 400 diameters must be made, care being taken that the grains are not brought to the point of development by the illumination that is required. A red filter (the Wratten and Wainwright filter used for isolating the red cadmium line of wave-length $614 \mu\mu$) is placed in front of the source of light (an automatic arc-lamp), and red-sensitive plates (panchromatic B) are employed; with these an exposure of 1 to 3 seconds is sufficient to give good microphotographs. The grains to be examined are placed on an ordinary microscope cover-glass. In order to obtain the grains spread out in a single layer the following procedure is adopted:

An ordinary commercial dry-plate is allowed to soak in distilled water for some hours in the dark or in a very dark red light. A small quantity of the emulsion is then placed on a thoroughly cleaned cover-glass and carefully warmed over an electrically-heated wire till it has almost reached the melting-point of the gelatine. The emulsion is then pressed into a very thin layer with the aid of a second cover-glass and the two

cover-glasses are separated from one another. The thickness of such a layer is a few thousandths of a millimetre.

Most of the preparations employed—"Emulsion Lumière sensibilité extrême"—exhibit crystalline grains 2 to 10μ in diameter, many of them being of hexagonal form—triangular with truncated corners. It remains to be seen whether the grains are tetrahedral or in the form of small plates. The "Kranzeder-Reform" plates exhibit somewhat finer grains, the diameter being less than 4μ .

After development with normal metol-hydroquinone developer the silver bromide grains exhibit the same relative positions, and their sizes and forms remain practically the same, except that some grains develop excrescences. The grains of the "Kranzeder-Reform" plates, however, develop into long drawn-out appearances. Paraphenylene-diamine developer gives rise to fine-grained negatives from coarse silver bromide emulsions. This is due to the fact that it reduces only some portions of the grains, the other portions not being affected even after strong illumination and lengthy development. Under certain conditions very dilute metol-hydroquinone developer acts in a similar manner. A "Lumière-blue-etikett" plate after development showed that each silver bromide grain was developed into a silver grain, although the plate appeared as clear as glass.

Further investigation was made on the connection between size of grain and sensitivity to light. Contrary to the usual opinion it was found that there is no clear connection between the two—the largest grains of an emulsion are not always the most sensitive. The effect of X-rays was also investigated.

J. S. A.

BOOK RECEIVED

"The Theory of Modern Optical Instruments." By Dr A. GLEICHEN. Translated from the German by H. H. ELMSLEY and W. SWAINE, with an Appendix by the Translators on Range-finders. Pp. xiii + 376. (London, His Majesty's Stationery Office, 1918.)